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13. ABSTRACT *(Maximum 200 Words)*

Stereo Imaging is very important in the analysis of aerial imagery. The proposed project considers the problem of stereo matching using wavelet transforms. In our method, the wavelet transformation of a signal using a wavelet basis with nth vanishing moment is regarded as nth edge of the signal after some smoothing operation. We then analyze the physical meaning of each channel of the sub-images decomposed by a wavelet. Based on the analysis, we proposed a hierarchical algorithm that combines both feature-based and pixel-based methods together, to compute the disparity of the binocular stereo image. We have tested the proposed algorithm on a large number of natural and synthetic scenes. Our method is effective on stereo image pairs with large disparities that is a case, which is very important for applications as structure from stereo. We also proposed a general wavelet-based hierarchical matching scheme which involves a dynamic detection of interesting points as feature points at different levels of sub-band images via wavelet transform, and adaptive threshold selection based on compactness measures, a guided searching strategy for the best matching from coarse-to-fine levels. Also, some other problems are investigated including the extraction of 3D lines from range images, and dynamic shape retrieval by curve matching and active contour models, and applications of fuzzy logic to project selection.

The project falls under the Nebraska DEPSCOR Research Priority Area of Information and Communications Science and Technology awarded by the Ballistic Missile Development Agency (BMDO) and it is administered through the AFOSR.

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- Title of project: "Automatic Target Recognition, Wavelet Transforms and Stereo Matching"
- Program manager: **Dr. Jon A. Sjogren**
- Total duration of project: April 1, 1998 — March 31, 2001. No-cost extension till March, 2002.

1 Status of Effort

The project was started in April, 1998 and completed in December 2001. The PI also collaborated with Professor Azriel Rosenfeld on geometric problems in vision that have applications in object recognition and automatic target recognition. Several journal papers have been developed out of the research carried out in this project and also a number of conference presentations were given (see the list given at the end).

During this period, the PI has been elected a Fellow of IEEE for his contributions to image processing and image understanding.

2 Stereo Correspondence: A Wavelet-based Approach

We have developed a new un-calibrated hierarchical method to solve the correspondence problem using real discrete wavelet transformation (DWT). The wavelet transformation of a signal using wavelet basis with nth vanishing moment can be regarded as nth edge of the signal after some smoothing operation. We then analize the physical meaning of each channel of the sub-images decomposed by wavelet. Based on the analysis, we propose a hierarchical algorithm, which combines both feature-based and pixel-based method together, to compute the disparity of the binocular stereo image.

The implicit assumption of all stereopsis technique is that the conjugate pairs in the stereo images have been determined. Therefore, detecting conjugate pairs is a central problem, known as the correspondence problem, for stereo vision. Based on the data source used, current methods of finding corresponding points can be divided into two categories:

- Calibrated: The basic idea of this method is to match features (such as zero-crossings, gradient peaks in the pair of images under a group of contraints, particularly epipolar constraints. (Other constraints include: local constraints, orientation constraints, length constraints, uniqueness constraints, order constraints, continuity constraints. In this method,

the precise description of position, orientation, and other calibration data of the two cameras are required.

- Un-calibrated: This method solve the correspondence problem only by a pair of images without using any constraint provided by the calibration information of the cameras. The implementation of this method can be further divided into the following classes:
  - Area-based stereo, which essentially assumes that the disparities are constant;
  - Feature-based stereo, which uses zero-crossing, gradient peaks, line segments, structual descriptions, regions, lines, edges, and so on as matching primitives;
  - Pixel-based stereo, which basically tries to minimize the left and right image measurement (intensity) differences subject to a smoothness constraint.

In many practical applications, either the camera calibration data, or the precise description of position and orientation of the camera cannot be obtained. In this case, the un-calibrated method is more attractive.

Previous related works: The traditional un-calibrated methods are either unaccurate (area-based), computationally expensive (feature-based), or slow converging (pixel-based). Recently, J. Magarey and A. Dick proposed a hierarchical method for stereo image mathcing using complex wavelet. The basic idea is to use the phase information, which is obtained from all sub-images at each scale level decomposed by complex discrete wavelet transformation (CDWT). Because one image will be decomposed into six sub-images by CDWT, rather than four sub-images by DWT, the computational expense is relatively higher. In addition, the phase signals sometimes are very sensitive to spatial position and to variations in scale. Therefore, additional post processes such as sigularity detection and regularization are needed to prevent the disparity field from corruption, which makes their methods more complicated and further increases the computation. Heping Pan also presents a similar method — bottom-up wavelet multiresolution analysis and top-down image matching using complex conjugate wavelet pyramids. Instead of explicit features such as points, edges, regions, etc., the so-called *uniform full-information* representation is used as implicit feature vectors. Local parallax continuity and generic pattern matching are added to further increase the robustness of the result. G. Q. Wei proposed another hierarchical method for stereo image mathcing based on Gaussian basis functions. The main idea is to use both intensity and gradient information of the image to formulate an cost function, and compose the disparity by muti-scale Gaussian basis functions to try to minimize the cost. However, the convergence rate is not guaranteed in some case, and the method requires that the disparity in Y direction be zero. This limits its usage in the uncalibrated stereo matching, in which case the zero disarity in Y direction is always not guaranteed.

In the proposed un-calibrated hierarchical method to solve the correspondence problem using real discrete wavelet transformation (DWT), we first show that the wavelet transformation of a signal using wavelet basis with nth vanishing moment can be regarded as nth edge of the signal after some smoothing operation. We then analyze the physical meaning of each channel of the sub-images decomposed by wavelet. Based on the analysis, we propose a hierarchical algorithm, which combines both feature-based and pixel-based method together, to compute the disparity of the binocular stereo image.

One of the important reasons that we use wavelet analysis is that there exists fast DWT algorithm for 2-D discrete signal such as digital image (as described in standard works by Mallat. By being convoluted with a 1-D FIR wavelet basis pair in horizontal and vertical direction, and down-sampled, an image can be efficiently decomposed into the four sub-images, i.e. by DWT, we can

efficiently obtain the muti-scale intensity and gradient description of the original image. It is worth mentioning that because here the wavelet is used as a pair of filters to decompose an image into four coarser sub-images, the selection of the wavelet base (filters) is not arbitary. Both unsymmetric wavelet base, which causes the nonlinear deviation of the sub-images, and the wavelet base with long filter, which causes the boundary effect, are not appropriate for our purpose. Fortunately, there are many symmetric wavelet bases with short filter exist, such as Meyer wavelet, Symlets wavelet (near symmetric), Coiflets wavelet (near symmetric), B-splines biorthogonal wavelets, etc.

It should be pointed out that our hierarchical method is different from a structural hierarchical method such as that described by Venkateshwar and Chellappa (published in the *International Journal of Computer Vision*, 1995). The latter starts matching at high-level features such as lines, vertices, surfaces, etc. Then the matching is implementd by labeling, structural grouping, perceptual groupiong, super-grouping, etc. under unqueness constraints, ordering constraints, topoolgical constratints, etc. Our method avoids the complicated processes of feature detection, labeling, grouping, etc. It directly expolits the hierarchical representation, including both area and geature information, provided by the wavelet decompostion, to do fast and yet accurate matching.

We have tested the proposed algorithm on a large number of natural and synthetic scenes. In our technical paper qualitative and quantitive comparisons are made with three other published methods. In our experiment, we mainly use grids to show the quality of disparity. The cross point in the left image matches the correspoinding point in the right image. We find that it is hard to thell the quality of a disparity from its gray-level images since even poor matching sometimes results in good shapes in the gray-scale image. In our implementations, one of the methods used any form of calibration informationm about the test image pairs. We found that our method was a little slower thatn the fasted method but it had the highest accuracy in terms of the RMS of disparity error for all the image pairs that we tested. Also, experiments showed that our method is effective on an image pair with large disparity which is important for applications as structure from stereo.

In conclusion, we remark that our method, based on the discrete wavelet transform (DWT), provides a way of combining these two methods into a single hierarchical process. First, the two images are decomposed by wavelets at a coarse level. Hieracrchical area-base matching using the approximation channel of the decomposition is combined with hierarchical feature-base matching using the horizontal and vertical channels of decompositiomn. The matching results from the coarse level are propoaged to finer levels by using a fast DWT algrotm together with a hierarchical matching strategey our method proveides high accuracy and high speed. Because it discards the detail channel, which usually coantains noise, our method has high robuistness against point nooise. Our experiments showed good matching performance for a synthetic image pair, real indoor and outor image pairs, and an aerial image pair with high noise. In comparison with the other three methods, our method had the best performance-cost ratio.

- A refereed conference paper has been published in the Proceedings of the *International Conference on Pattern Recognition* (ICPR'2000), held in Barcelona, Spain in September, 2000. We have also submitted a journal paper based on this work that is currently under review.

3 Wavelet-Based Hierarchical Matching Scheme

- A full-length journal paper describing our work has now been published in the September, 2000 isuue of the **IEEE Transactions of Image Processing**. This paper has been cited in the second edition of a well known text on image processing and also in a recent US patent:

1. R.C. Gonzalez and R.C. Woods, *Digital Image Processing*, second edition, Prentice-Hall, NY. (Cited on p. 404 and also in the bibliography at the end of the book.)
2. Laumyer, et al., Method and apparatus for identifying objects depicted in a video stream, US Patent No. 6,266,442. Issued on July 24, 2001.

Image matching, which measurs the degree of similarity between two image sets that are superimposed on one another, plays an important role in many areas such as image nalaysis and computer vision. The images to be matched are required to go through a number of operations before the similarity is determined. These operations include feature extraction, distance transformation, similarity measurement and searching for the best match. Thus, an effective approach to image matching concerns with the following key issues: what kind of features are used for matching? What is the criterion for best matching? How to find the best matching?

We have developed a wavelet-based, high performance, hieararchical scheme for image matching which includes

- a dynamic detection of interesting points as feature points at different levels of subband images via wavelet transform.
- an adaptive thresholding selection based on compactness measures of fuzzy sets in image feature space
- a guided searching strategy for the best matching from coarse level to fine level.

In contrast to the traditional parallel approaches which rely on specialized parallel machines, we explored the ptential of distributed systems for parallelism. The proposed image matching algorithms were implemented on a network of workstation clusters using parallel virtual machine (PVM). The results show that our wavelet-based hierarchical image matching shme is efficient and effective for object recognition.

Our method involves using a guided searching scheme to quickly lead a matching process to the most liekly portion of the target image. This schme can speed up the matching process, especially when the sixe ration between a target image and a template image is big. Apoart from the guided hierarchical searching, we replaced edge points with interesting points as image feature points to reduce the rddundant information because the matching speed is proportional to the number of points which need to be matched. We proposed a wavelet-based image matching scheme to achieve efficiency and effectiveness, which includes:

1. to apply wavelet transform to decompose an image into different levels of subbband images
2. to detect the interesting points as feature points at different levles,
3. to introduce a guided searching procedure to search for the best matching from coarse level to fine level.

The conventional interesting point detection techniques are all based on the detection of discontinuities in pixel properties. Thus they are not suitable for textured images because texture is characterized by its local features over some neighborhood rather than in pixel gray scale. We have extended the concept of interesitng point for general-purpose images. Instead of applying interesing point operatiors to the original gray-scale image, the detection of interesing points was performed

on the feature image converted from the original images. For the case of textured images, we adoped Laws's texture energy measurement to convert a textured image to a texture energy image for the detection of interesting points.

The identification of interesting points is based on the selection of threshold. When a feature image is regarded as a fuzzy set X of size $m \times n$ and L levels of feature measurements, we extend the fuzzy compactness approach of Rosenfeld and Pal to determine the optimal threshold value by minimizing the measurement of fuzziness. In contrast to the conventional measurement of fuzziness in a gray scale image, we apply the distance measurement to feature image rather than the measurement of fuzziness in gray scale.

A key issue in image matching is how to create an image feature pyramid for matching. Unlike most of the existing matching algorithms which detect edge points and perform matching in a resoulution pyramid, we apply a wavelet transform to decompose an image into a seris of subband images and replace the edge pints with interesting points for an image feature hierarchy.

For applying the PVM, an image is partitioned into subimages and distributed over nodes on the network. The local processing results such as two-dimensional matrix operation, feature detection and transformation for each subimage are merged over the entire images. We adopted a master/slave parallel programming paradigm. The master program controls the data processed by a number of slave programs. It can run one one machie and spawn copies of the slave programs to any number of nodes in the network. The slave programs are spawned by the master program at runm time.

The main steps of our method are as follows:

- *Discrete wavelet transform*: master node reeads in original images, master node segments the image data and sends each subimage data to indivial slave node; each slave node prforms wavelet transform under the coordination of the master node; the master node collects the result from slaves and genera an image pyramid of subband images.

- *Distance transform*: the master node assigns one quarter of the partitioned binary image to each corresponding slave node; each slave node initializes the subregion of the distance image based on the binary image; each slave node a distance transform mask to perform distance transform and the subregion of the final distance image is created; the master node collects the processed data from each slave node and combines them to create the distance images.

- *Matching procedure*: the master node assigns one quarter of the partitioned distance image and the interest images of the template to each corresponding slave node; each slave node imposes the image of the template over the distance image and calculate the root mean square average for optimization; each slave node passes a number of possible areas to the master node for further comparison.

- The master node outputs the final result of matching.

To evaluate the performance gain, a system was implemented on a group of networked workstations where PVM was used to provide a parallel execution environment. Based on the developed system, a number of experiments were carried out to measure the effectivelness of using the hierarchical approach in matching, and to measure the speedup of using parallel guided matching against using sequesntial matching. The impact of communication overheads in relation to message size is also investigated. The codes were wrtitten standard C and exectued on a network of Sparc stations under the UNIX operating system. The experimnental results confirm the effectiveness of the proposed method.

4 Investigations on Shape Analysis

4.1 Dynamic Shape Retrieval by Curve Matching and Snakes

The *Active Contour Model* provides an effective approach to link image boundary feature points by a continuous curve, the so-called "snake". The snake will position itself anong the feature points in a robust manner by stretching and bending which is controlled by the parameters in its enery expression . The parameters of elasticity control the smoothness of the snake curves.

We have developed a similar shape retrieval technique by coarse-to-fine curve matching and data mining techniques. The proposed method extends the concepts of conventional data warehouse and image database for effective image indexing. A image database warehouse schema is developed to integrate multiple shape features for hierarchical fast query processing. A guided search scheme is introduced, that combines the methods of invariant moments, 2D polygonal arch matching and B-spline curve matching, to search for the best similar shape in a hierarchical manner. The roposed method is applied to the tropical cyclone patern recognition by utilizing the active contour model (snake) to extend the tradional Dvorak technique for criical cyclone intensity analysis and forecasting from satellite imagery.

To avoid the blind searching for the best fit between the template pattern and all of the sample patterns stored in the image data warehouse, a guided search strategy is essential to reduce computational cost. We have proposed to partition along a dimension to facilitate a coarse-to-fine curve matching scheme for similar shape retrieval. We begin initial searching for the best similar shape matching with the dimension of invariant moments. Our similarity measurements method is based on the comparison of the Cosine distance of the proposed shape moment feature vectors for different samples after Gaussian mormalization. The candidates with small distance differences will be considered for fine matching based on 2-D polygonal arc matching a B-spline curve matching.

- Two refereed conference papers have appeared in the Conference Proceedings, based on two different aspects of the work reported in this section; one paper at the *European Signal Processing Conference* held in September, 2000 in Tampere, Finland, and the other paper at the *International Conference on Pattern Recognition* (ICPR'2000), held in Barcelona, Spain in September, 2000. Also, a paper has been submitted to the *Inernational Journal of Computer Vision* that is currently under review.

4.2 Extraction of 3D Lines in Range Images

- This is a joint work jointly with Professor Azriel Rosenfeld, Dr. Scott Thompson both of the University of Maryland, and Mr. Haying Liu who was the graduate student supported by this grant. It has been published in the **Pattern Recognition Letters**.

The straight lines in the plane constitute a two-parameter family; for example, a line is uniquely determined by specifying its slope and its (signed) perpendicular distance from the origin. If edge or line fragments detected in the plane are mapped into (slope, distance) parameter space, collinear families of fragments will give rise to peaks in the parameter space. The mapping from the plane to the parameter space is called a *Hough transform.* Many variants on this idea have been used to detect lines, or other types of curves, in the plane.

In principle, the Hough transform concept can be extended to linear subspaces of n-dimensional Euclidean space, which can be regarded as intersections of hyperplanes. In particular, lines in 3D

space can be regarded as intersections of planes. The planes in 3D space have a simple three-dimensional parameterization; for example, a plane is determined by two direction cosines of its normal (two "slope" parameters) and by its (signed) perpendicular distance from the origin.

The Hough transform does not seem to have been extended to lines in 3D space, perhaps because such lines constitute a four-dimensional parameter space. For example, a line is determined by two of its direction cosines and by the Cartesian coordinates of its intersection with a plane through the origin perpendicular to it. (This representation uses two "slope" parameters and two "intercept" parameters; the analogous parameterization of a line in the plane would use its slope and the coordinate of its intersection with a line through the origin perpendicular to it.) Using this 4D Hough space to detect arbitrary collinear sets of edge or line fragments in 3D space would be cumbersome. Man-made environments, however, often contain many straight edges or lines that belong to a small number of parallel families. (This is true, for example, for the edges defined by the walls, floor, ceiling, doors and windows in a room.) These families can be detected as peaks in the slope parameter space, which is only two-dimensional (the direction of a 3D line is determined by two direction cosines). For each such peak, the individual lines can then be detected as peaks in the intercept parameter space, which is also only two-dimensional. Thus if the straight edges or lines in a scene are all oriented in only a few directions, this method can be used to detect them at moderate computational cost.

The 4D Hough transform approach cannot be applied to detecting straight edges or lines in two-dimensional images of a scene, because such images do not provide full 3D information about the lines. Full 3D information is available in 3D images, e.g. obtained by reconstruction from projections; but most of the available 3D images are images of the human body, which does not contain planar surfaces or straight edges. A better source of 3D information about straight edges or lines is range imagery of man-made objects. At an occluding straight edge in such an image there is an abrupt change in range; at a dihedral angle (a straight edge where two planes meet), there is an abrupt change in the rate of change of range. Thus these types of edges give rise to high values in the first or second derivative of range in the direction acros the edge. Standard range sensors provide 3D information about the locations of visible points in the scene; in particular, about the locations of the high-derivative edge elements in the scene.

4.3 Hough Transforms and Correlations

- This is a joint work with Professor Azriel Rosenfeld and Dr. Isaac Weiss from the University of Marylyland.

- A paper based on this work has appeared in 2001 as a book chapter in the Springer Lecture Note Series; one paper has been accepted for publication in the *Pattern Recogntion* and yet another paper is under review in a journal.

In 1962 Hough patented a method of detecting collinear sets of points in an image by applying a linear point-line mapping to the image. Such a mapping, which in projective geometry is called a *correlation*, takes collinear points (points that all lie on the same line) into concurrent lines (lines that all pass through the same point). Thus if the image contains n collinear points, the mapping takes these points into n concurrent lines; hence if the mapping is additive, it produces a peak of height n at the point where all the lines intersect. Over the past 30 years, many variations on and generalizations of Hough's idea have been proposed. These methods generally involve mappings f from the plane into some space, such that if many points of the plane belong These methods generally involve mappings f from the plane into some space, such that if many points of the

plane belong to a locus of a given form, their images under f give rise to a peak in the space. Such mappings are called *Hough transforms.* There are many types of Hough transforms. Because of the great variety of Hough transforms, not much attention has been paid to Hough's original definition, which was based on a linear point-line mapping from the points of the plane into the lines in the plane. A recent paper by Aguado et al. calls attention to the relationship between Hough's definition and the concept of point-line duality in projective geometry, but does not fully discuss the mathematical properties of point-line mappings.

Our work deals with point-line (and line-point) mappings and their properties. We classify linear point-line mappings in terms of properties of their matrices, and discuss ways in which the matrices can be put into canonical form. We also study point-line mappings that are not necessarily linear, but that preserve point-line incidence. We discuss useful geometric properties of such mappings, especially in cases where their matrics define nonempty conics. Finally, we show that any point-line mapping defines composition operations on points (or lines), and discuss how the algebraic properties of these compositions are related to geometric properties of the mappings.

Point-to-line (PTLMs) have several uses in image analysis and computer vision; a linear PTLM was used by Hough to detect sets of collinear points in an image, and it can be shown that three lines L, M, N in the plane are the images of three mutually perpendicular lines in space if and only if there exists a PTLM thatt maps the vertices of trianges LMN into their opposeite sides. We have investigated a variety of mathematical properties of PTLMs. We show that any PTLM that has an incidence-symmetry property must be linear and must have a symmetric matrix. We also diucusss PTLMs of polygons, and show how to construct polygons whose vertices are mapped into their sides by a PTLM. Also, we show how a PTKM can be used to define binary opeations on points, and discuss algebriaic properties of these operations.

4.4 Convexity

- This is a joint work with Professor Azriel Rosenfeld of the University of Maryland. This work has recently appeared in the *Pattern Recognition Letters.*

Goodman and Pollack (1995) have introduced a concept of convexity for sets of translates of linear subspaces in n-dimensional space; in particular, their definition applies to sets of lines in the plane. Recently, Rosenfeld (1995) proposed two ways of defining geometric properties (such as convexity) for sets of lines — one in terms of properties of the corresponding sets of points in Hough space, and the other in terms of point/line incidence. The present work compares the three definitions, as well as a fourth definition which is a weakened version of Rosenfeld's incidence definition. We show that the Hough definition is incomparable with the other three, but that the incidence definitions imply the Goodman-Pollack definition.

Convexity is a basic concept in geometric shape analysis. A set of points in the Euclidean plane (or in a higher-dimensional space) is called *convex* if the line segment joining any two points of the set is contained in the set. After points, the next simplest geometrical structures are lines and it is thus of interest to extend the definition of convexity to sets of lines. The Euclidean plane is usually considered as a set of points, and geometric concepts such as convexity, connectedness, area, etc. are defined for subsets of the points. However, the plane can also be considered as a set of lines; this view is consistent with the well-known concept of "duality" in projective geometry, where all results involving incidence properties of points with lines have their duals involving incidence properties of lines with points. A line in the plane can be specified completely by two parameters, and so we can map the line to a unique point in a two-parameter space, commonly called a *Hough*

space. If the Hough space is properly defined, this correspondence between the lines in the plane and the points in the Hough space is one-to-one and continuous. We can then define a set of lines on the plane to be "convex" if the corresponding set of points in Hough space is convex. It follows immediately from this definition that a single line is convex but a finite set of two or more lines is never convex. It was proved earlier by Rosenfeld that the pencil of lines through the origin is convex and the set of all lines parallel to a given line is convex, but that no other pencil of lines is convex. It is well known that convexity of points in the plane is not a topological concept, so it is not expected that convexity of lines should be a topological concept. However, when we attempt to derive geometrical properties from a proposed defintion, we need to describe them in the context of a topological foundation.

It would be of interest to formulate a Hough space definition for sets of lines in 3-space, and it might also be interesting to consider incidence definitions in which larger intersections are required. Extending our results to modifications of convexity (e.g., orthoconvexity) or to fuzzy sets of lines might also be of interest.

5 Project selection using fuzzy logic

We also took up investigations on certain topics that are of interest to AFOSR. The topic of hierarchical decision making for operational test and evaluation is of significant interest to the DoD. For example, Major Suzanne M. Beers, USAF of the Air Force Operational Test and Evaluation Center, has recently investigated a methodology called the "Intelligent Decision Architecture" and presented her results at the Fifth IEEE International Conference on Fuzzy Systems, 1996.

- This work (co-authored by the PI with his graduate student) has been published as a full-length paper in the **IEEE Transactions Engineering Management** in 2000.[1]

Ambiguity is usually present in the information or evidence that we use. Project selection is a complex decision making process involving a number of critical factors. The classical methods of project selection mostly ignore the behavior of people in organizational settings and also the different cultural and functional backgrounds of the project managers. Fuzzy logic is a powerful tool to handle imprecise data. Fuzzy expressions are more natural for humans than rigid mathematical rules and equations. The fuzzy reasoning system makes no global assumptions about the data. To investigate the project selection problem under uncertainty, we applied the powerful technique of fuzzy logic. We first decided what variables of the problem to use and described those variables with adjectives that make sense and formed rules which describe the relationships between the results we wanted and the available data.

Our approach to project selection is done in terms of uncertainty reduction. We select a set of criteria for the selection of projects. This choice takes into light an implicit classification of decision making aspects. The elements of weighing (or priority) vector are considered as functions of the levels of interacting criteria. We look at the attributes where each attribute has values that may not be numerical. The decision mechanism is constrained by the uncertainty inherent in the determination of relative importance of each attribute element and we address the classification of alternatives through an expert evaluation of the degree to which each element is contained in

[1]This work has been cited in the following recent paper: D.N. Zhou et al., "Journal Quality Assessment: An Integrated Subjective and Objective Approach," **IEEE Trans. Engineering Management**, vol. 48 (4), pp. 479-490 (2001).

each available alternative. To specify an optimal alternative, the expert would have to choose by compromising according to the degree to which different attributes have distinct values, and the optimum or ideal is formed by the relative weights for each attribute's elements combined over all the attribute membership functions. The best alternative is defined by a set of attributes rating best. To solve a problem using fuzzy logic first we decided what variables of the problem to use. Then, we described those variables with adjectives that make sense. Next, we described what we mean by each adjective, that is, we draw a fuzzy graph on which the X axis is the range of the variable and the Y axis represents the degree to which the word describes a value in the range. Finally, we formed some rules that describe the relationships between the data available and the results we wanted. Because the adjectives we used to describe the data are vague and inexact, our rules look like something we would like to tell another person.

In our case study, we have considered the problem of selecting a software product when uncertainty is present and we propose a system based on fuzzy logic. The problem of software product selection is of significant interest because of the multitude of software available in the market and also there are a number of critical factors such as cost, risk and uncertainty that are involved in the process of selection. We have applied the proposed system to the problem of selection for database software packages. Because the adjectives used to describe the data are vague and inexact, our rules often look like something we would like to tell another person. Our proposed method could be easily applied to many other project selection problems where uncertainty is present.

6 Personnel Supported

- Staff
  1. Dr. Prabir Bhattacharya, PI (2 summer months).
  2. Haying Liu, Ph.D. student (12 months)
- Consultants
  1. Professor A. Rosenfeld, Honorary Consultant
  2. Professor R. Chellappa

The PI made several trips to the Center for Automation Research, University of Maryland to consult with these two very eminent researchers which was very beneficial to the project.

7 Interactions/Transitions

The results from our effort could be used in developing technology for automatic target recognition by providing hierarchical matching of stereo images, image segmentation and multi-dimensional signal processing. We have discussed part of our technical efforts with Mr. Vincent Velten of the WL/AARA, of the Wright-Patterson AFB, Dayton, Ohio.

8 Honors/Awards

1. **Elected a Fellow of IEEE**, November, 2001. "For contributions to mathematical and geometrical methods in image processing and understanding"[2].

2. National Lecturer of the Association of Computing Machinery (ACM) during 1996-99.

3. Distinguished Visitor of the IEEE Computer Society during 1996-99.

4. The PI received an award from the College of Engineering and Technology, University of Nebraska-Lincoln for the Highest Excellence in Research at the Full Professor level, in May, 1999.

5. Editorial Activities:

   (a) Member, editorial board of "Pattern Recognition" during 1994-present.
   (b) Associate Editor, "IEEE Transactions on Systems Man and Cyberneitcs" during 2000-present.
   (c) Associate Editor, "Pattern Recognition Letters" during 2001-present.
   (d) Associate Editor, "International Journal of Pattern Recognition and Artifical Intelligence" during 2001-present.
   (e) Advisory Editor, "Machine Graphics and Vision" during 2001-present.

9 Participation/presentations at meetings, conferences, seminars, etc.

9.1 Membership of Program Committees of Conferences

1. IEEE Computer Vision and Pattern Recognition Conference (CVPR99), Fort Collins, Colorado, 1999.

2. 6th IEEE International Conference on Image Processing, Kobe, Japan, 1999.

3. SPIE 21st International Conference on Applications of Digital Image Processing, Denver, Colorado, 1999.

4. 3rd International Conference on Computational Intelligence and Multimedia Applications, New Delhi, India.

5. 32nd International Symposium on Automotive Technology Automation, Conference on Robotics and Machine Vision," Vienna, AUSTRIA, 1999.

6. 6th IEEE International Conference on Image Processing, Kobe, Japan.

7. 4th IEEE Southwest Symposium on Image Analysis and Interpretation, Austin, Texas, 2000.

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8. 33rd International Symposium on Automotive Technology Automation, Conference on Robotics and Machine Vision, Dublin, IRELAND, 2000.
9. 6th International Conference on Computer Graphics and Image Processing, Warsaw, Poland, 2000.
10. SPIE 22nd International Conference on Applications of Digital Image Processing, San Diego, CA, 2000.
11. IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing, Baltimore,MD, 2001.
12. IEEE International Conference on Multimedia and Expo (ICME'2001), Tokyo, Japan.
13. IEEE International Conference on Multimedia and Expo (ICME'2002), Lausanne, Switzerland.

9.2 Chairing Technical Sessions in Conferences

1. International Conference on Pattern Recognition (ICPR2000), Barcelona, Spain, September, 2000. Chaired a session in the computer vision track.
2. SPIE 22nd International Conference on Applications of Digital Image Processing, Denver Colorado. Chaired two sessions.

9.3 Presentations in Conferences

1. H. Liu, "Hierarchical Stereo Correspondence Using the Wavelet Transform," *Proc. of 15th Internat. Conf. Pattern Recognition* (ICPR2000), Barcelona, Spain, September, 2000, pp. 114-118. (Publisher: IEEE Press.)
2. J. You and P. Bhattacharya, "An Effective Image Representation for Visual Information Retrieval," *Proc. 10th European Signal Processing Conf.* (EUSIPCO00), Tampere, Finland, September 2000, pp. 1381-1385. (Publisher: IEEE Press.)
3. J. You and P. Bhattacharya, "Image Retrieval Using Contour Matching, and Active Contour Model," *Proc. of 15th Internat. Conf. Pattern Recognition* (ICPR2000), Barcelona, Spain, September, 2000, pp. 1035-1038. (Publisher: IEEE Press.)
4. D. Heisterkamp and P. Bhattacharya, "Object and Motion Recognition using Plane Plus Parallax Displacement of Conics," *Proc. 14th International Conf. Pattern Recognition* (ICPR'98), Brisbane, Australia, August, 1998, pp. 751-753. (Publisher: IEEE Press.)
5. J. You, S. Hungnenahally, A. Sattar, and P. Bhattacharya "Image Transforms in a Parallel Virtual Machine Environment," *Proc. 2nd IEEE International Conf. on Intelligent Processing Systems*, Gold Coast, Australia, August 4-7, 1998, pp. 173-176.
6. J. You, P. Bhattacharya and S. Hungnenahally "Real-time Object Recognition: Hierarchical Image Matching in a Parallel Virtual Machine Environment," *Proc. 14th International Conf. Pattern Recognition* (ICPR'98), Brisbane, Australia, August, 1998, pp. 275-277.
7. Y. Wang and P. Bhattacharya, "An Algorithm for Finding Parameter Dependent Connected Components of Gray Images," *Proc. of 51st Annual Conference of the Soc. of Imaging Technology*, pp. 380-385, Portland, Oregon, May, 1998.

8. K. Qian, S. Cao and P. Bhattacharya, "Skeletonization with Hollow Detection on Gray Images by Gray Weighted Distance Transform," *Proc. 21st SPIE Conf. on Applications of Image Processing*, San Diego, CA, July, 1998, SPIE vol. 3460, pp. 746-751.

9. J. You and Prabir Bhattacharya, "A Wavelet-based Approach to Fast Similar-shape Retrieval," *Proc. Internat. Conf. on Imaging Science, Systems, and Technology* (CISST'99), Las Vegas, Nevada, July, 1999, pp. 250-256.

10. Y. Wang and P. Bhattacharya, "Finding the Parameter Dependent Connected Components of Gray Images," *Proc. 21st SPIE Conf. on Applications of Image Processing*, San Diego, CA, July, 1998, SPIE vol. 3460, pp.135-144.

11. Y. Wang and P. Bhattacharya, "Image Understanding with Connected Component Histograms," *Proc. Conf. Image Processing, Image Quality and Image Capture Systems*, Savannah, Georgia, April, 1999, pp. 367-372.

12. Y. Wang and P. Bhattacharya, "Component Histograms and Image Understanding," *Proc. 22nd SPIE Conf. on Applications of Image Processing*, Denver, CO, July, pp. 469-478, 1999.

13. K. Qian and P. Bhattacharya, "Polynomial Morphological Approach in Pattern Recongnition," *Proc. SPIE 9th Vusial Information Processing Conf.*, Orlando, FL, 2000, pp. 146-153, SPIE vol. 4041.

9.4 Interaction with DoD Laboratories

The PI visited the Wright Patterson AFB in 1998 and gave presentations on the work done in this project. Also, discussions with held with Mr. V. Velten of the Target Recognition Branch.

9.5 Consultative and advisory functions to other laboratories

None.

10 List of Journal Papers Published

1. J. You and P. Bhattacharya "A Wavelet-Based Coarse-to-Fine Image Matching Scheme in A Parallel Virtual Machine Environment," **IEEE Transactions on Image Processing**, vol. 9, no. 9 pp. 1547-1559 (2000).

2. P. Bhattacharya, "On the Dempster-Shafer Evidence Theory and Nonhierarchical Prioritized Aggregation of Belief Structures," **IEEE Transactions on Systems, Man and Cybernetics**, Part A, vol. 30, no. 5, pp. 526-536 (2000).

3. L. L. Machacha and P. Bhattacharya, "A Fuzzy-Logic-Based Approach to Project Selection," **IEEE Transactions on Engineering Management**, volume 47, no. 1, pp. 65-73 (2000)

4. P. Bhattacharya, H. Liu, A. Rosenfeld and S. Thompson, "Hough Transform Detection of Lines in 3D Space," **Pattern Recognition Letters**, vol. 21, no. 9, pp. 843-849 (2000).

5. P. Bhattacharya, and A. Rosenfeld, "a-convexity," **Pattern Recognition Letters**, vol. 21, no. 10, pp. 955-957 (2000).

6. P. Bhattacharya and A. Rosenfeld, "Convexity of Sets of Lines," **Pattern Recognition Letters**, vol. 19, pp. 1199-1205 (1998).

7. Y. Wang and P. Bhattacharya, "Hierarchical Stereo Correspondence Using Features of Gray Connected Components," **Machine Graphics and Vision**, vol. 8, no. 1, pp. 19-54 (1999).

8. P. Bhatacharya, A. Rosenfeld and I. Weiss, "Point-to-Line Mapings and Hough Transforms," in **Digital and Image Geometry** (ed. G. Betrand *et al.*) Lecture Notes in Computer Science Series (LNCS), vol. 2243, pp. 185-206, Springer-Verlag, New York, 2001.

9. P. Bhatacharya, A. Rosenfeld and I. Weiss, "Geometric and Algebraic Properties of Point-to-Line Mappings," **Pattern Recognition**, accepted for publication.

10. P. Bhatacharya, A. Rosenfeld and I. Weiss, "Point-to-Line Mappings as Hough Transforms," submitted for publication.

11. H. Liu and P. Bhattacharya, "Stereo Matching Using Discrete Wavelet Transforms," submitted for publication.

12. J. You and P. Bhattacharya, "On Hierarchical Content-Based Image Retrieval by Dynamic Indexing and Guided Search," submitted for publication.

11 New Discoveries, inventions, or patent disclosures

The discoveries made in the project are reported in the unclassified papers cited above.